AN INVESTIGATION OF THE CONTROL OF SOUND IN VENTILATING PIPES

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY WALTER BOATMAN WORSHAM

ENTITLED AN INVESTIGATION OF THE CONTROL OF SOUND IN VENTILATING PIPES

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS IN PHYSICS

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*Required for doctor's degree but not for master's

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I. PURPOSE OF INVESTIGATION

The purpose of this investigation is to study the action of sound in ventilating pipes and to seek devices that will serve for its control.

The insulation of sound in buildings is complex. Soundproofing investigations carried on thus far have been concerned chiefly with the action of sound-proof walls, doors, and similar constructions; little attention having been paid to the transmission of disturbing noises through the ventilation ducts. Without some efficient control of the sound through these pipes, it is a waste of effort to construct sound-proof walls, install patent doors or other contrivances for insulation.

II ACTION OF SOUND IN VENTILATING PIPES

Sound waves consist of alternate condensations and rarefactions in the air. The air particles move back and forth over very short distances in transmitting the waves; the action being entirely different from the passage of water or air through a pipe.

Sound waves are transmitted from one room to another through heating and ventilating pipes very much as sound is carried through speaking tubes. Instead of spreading out in spheres as they do in the open air, the sound waves are confined within the duct by reflection at the sides so that they travel forward with a comparatively small decrease in amplitude, the wave front remaining the same throughout. The velocity of propagation is independent of the pressure of the air; it increases with the temperature of the air, and is propagated quicker with than against the air current, the speed in the first case being the sum and in the second the difference of that of sound and the air current.[1]

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1. Barton, E.H. "Text-Book on Sound", Sec. 173.

III PREVIOUS INVESTIGATIONS

Sound proofing has engaged the attention of architects and scientists for years but little effort has been made to devise plans for sound control in ventilating pipes.

Hiram Percy Maxim, of Hartford, Connecticut, made a study of the problem and later patented what he termed a "Building Silencer".[2] This device consists of a large chamber which is to be placed on the top of a building and is designed in such a manner that all the air entering or leaving the building must pass through it. It is lined with some sound deadening substance and fitted with coils and baffles arranged in such a manner as to transform the energy of the sound into heat energy. It was designed to eliminate outside noises rather than to stop the transmission of sound between rooms.

Professor Wallace Clement Sabine, of Harvard University, studied the effect of air currents and of temperature in connection with his investigations of architectural acoustics.[3] He concludes that the problem of properly heating and ventilating a room is a difficult one from an acoustical standpoint and merits consideration. He advises that the temperature of a room should be kept homogeneous and thinks that this condition of homogeneity is best secured by that system of ventilation known as "distributed floor outlets".

Dr. Paul E. Sabine, Geneva, Illinois[4] described briefly the system installed in the Riverbank Laboratories and brought out several important factors regarding sound control in ventilating systems. His method is very similar to that devised by Maxim.

Professor Floyd Rowe Watson, of the Physics Department, University

2. Patent No.1,289,853, dated December 31, 1918.
3. Sabine, W.C. "Architectural Acoustics", Eng.Rec., June 1910.
4. Proceed. Ill. State Acad.Sci., April 1923.

of Illinois, has studied this problem in connection with his work on architectural acoustics.[5] Dr. Watson recommends that any necessary openings for pipes, ventilators, etc., be placed in outside or corridor walls where a leakage of sound will be less objectionable; and that ventilation systems should be arranged so as to minimize the possibility of the transmission of sound from room to room.

Other investigations which have been carried on and which deal more or less directly upon this subject are as follows:

Naval Constructor Elliott Snow, U.S.N., in his bulletin[6] on "Voice Pipes" describes tests made to determine the efficiency of voice tubes on battleships. His chief conclusions are that there is a loss of intensity in tubes of small diameter due to the friction in the directional length of the tube; the yielding of the material from which the tubes are made, and leakage of air through the walls of the tubes or through the joints; (These conclusions were suggested by Professor W.C. Sabine) also, that sound is strengthened by the neighborhood of a sonorous body, and that pipes should be made of a non-vibrant material, they should be as smooth as possible inside and thick enough to prevent losses from "panting".

Helmholtz and Kirchoff investigated the velocity of sound in pipes, the former taking into consideration the friction alone, while the latter considered also the exchange of heat between the pipe walls and the contained gas, and both came to the conclusion that the difference between the velocity of sound of frequency N in free air and in a pipe of diameter r, is inversely proportional to r, and inversely proportional to the square root of N.[7]

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5. Watson, F.R. "Sound-Proof Partitions", Bull.127 Eng. Expt. Sta.
6. Snow, Elliott, "Voice Pipes", U.S.N. Inst.Proc., Vol.35, No.3.
7. Capstick, J.W. "Sound", Sec.268.

Regnault made an extensive series of observations of the velocity of sound in pipes and found that the velocity approaches a limit as the sound grows fainter, the limit being lower for narrow pipes than for wide ones. The limiting velocity was the same for all sources of sound.[8]

Capstick brings out the fact that there would be some reflection if a pulse traveled along a tube which had a sudden change of diameter, for example, if a compression starts from A (Fig.1) and travels

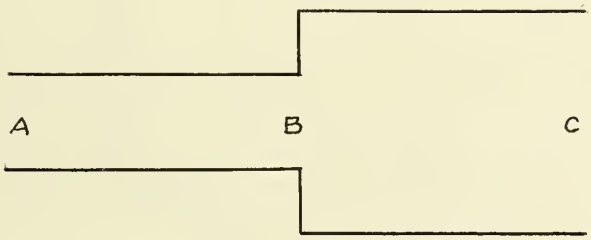


Fig.1

to the right, it meets with lessened resistance on reaching B, overruns itself, and part of its energy is reflected back to A in a rarefaction. If the compression starts from C and travels towards the left, it meets a greater resistance on reaching B, and part of its energy is reflected back to C in a compression. In each case part of the energy goes on and part is reflected, and the amount reflected depends on the relative cross sections of the two parts of the tube. If there is little change of section there is little reflection.[9]

The author made a study of the action of sound waves in register boxes designed to connect each room with the vent pipes. These register boxes are made larger than the pipes to which they

8. Barton, E.H. "Text-Book of Sound", Sec.478.
9. Capstick. "Sound", Sec.28.

are connected so as to make the net free area of the register or grill equal to the area of the pipe. This will require a register having a 50% free area to be twice the size of the duct as, for example, an 8" x 18" duct will have a 16" x 18" register as shown in Fig.2. This enlargement brings out the point made by Capstick as described above. For this investigation of the sound-waves, special

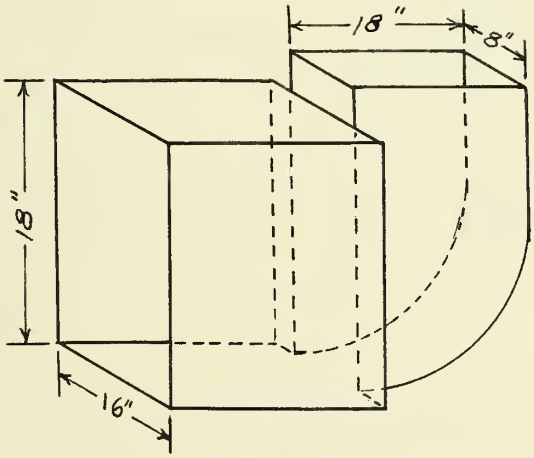
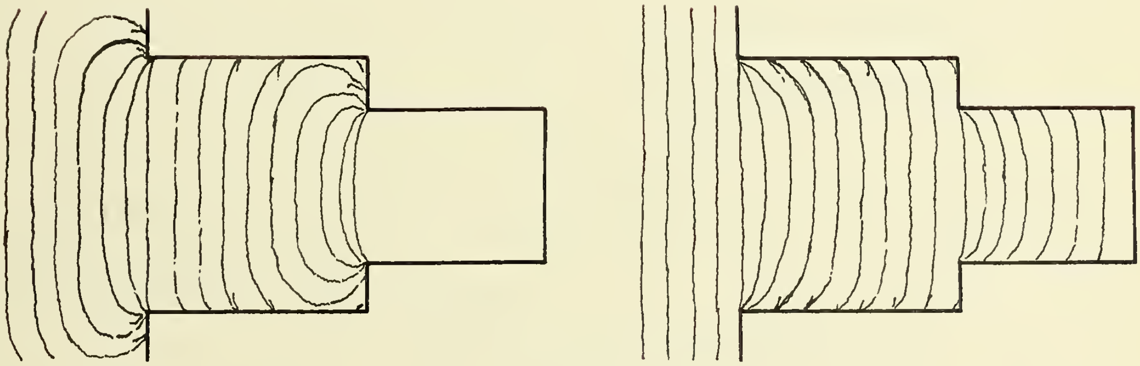


Fig.3

apparatus was devised, consisting of a tank with a glass bottom on which the outline model of these register boxes was placed. Water was then poured in the tank and ripple waves generated by a stream of compressed air which was interrupted by passing through a circle of holes in a rotating disc so that the puffs of air impinged periodically on the water surface. The waves were made visible by flashes of light passing up through the tank and forming a shadow of the waves on a frosted glass. Information thus gained by these water waves could be useful in predicting the similar action of sound waves in ventilation pipes.

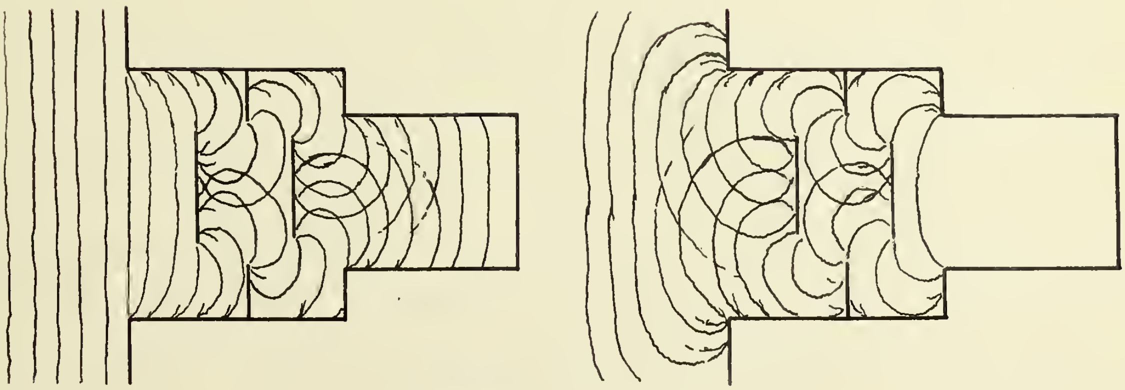
The current of air through the register box scarcely affects the sound waves since the velocity of the air is only about 0.08 meters per second, while the velocity of sound under normal conditions is about 337 meters per second. Observations taken by means of this

apparatus showed in a general way that the sound waves passed through the register box as shown in Fig.3. A being the case where sounds were entering the register box through the vent pipe, and B from the room in which the box was located. The effect of a series of baffles



A Fig.3 B

on the sound waves was then tried out in the ripple wave machine as shown in Fig.4. A showing their general effect upon entering the register box from the room, and B their effect upon sound waves entering the box from the vent pipes.



A Fig.4 B

V.W. Page shows that it is not only difficult to muffle the gases of a gasoline engine so that there will be little noise to the exhaust but it is quite a problem to do it without producing the back pressure in the muffling device that will cause a serious loss

of power. Various devices are installed in these mufflers such as concentric chambers, perforated baffle plates, and expansion chambers.[10]

L.A. Harding and A.C. Willard in their theory of ventilation likewise bring out many points which research men could use when investigating problems of this kind, such as the circulation of air in a building; the effect of locations of inlets and outlets on air distribution in rooms; the effect of high velocities in pipes and through grills; friction in various size pipes, elbows, square turns, and enlargements in pipe areas.[11]

IV EXPERIMENTAL INVESTIGATION

1. General Method.- A standard sound generated in one room passes through the ventilation pipes to other rooms where observations are taken. Absorbing devices are then introduced and the observations repeated.

a. Source of Sound.- In an investigation of this kind a source of sound should be chosen which will remain constant. It should also be capable of variation in pitch in order to furnish a more complete test. Voice, piano, and other sources of this nature are not satisfactory because they give complex sounds that are not constant. Tuning forks or tone variators are more suitable because they may be kept quite constant, and different pitches may be used. A tone variator of pitch 512 was finally selected as the source for this investigation.

b. Receivers.- A number of instruments and devices are available as receivers.

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10. Page, V.W. "The Modern Gasoline Automobile".
11. Harding, L.A. and Willard, A.C. "Mechanical Equipment of Buildings."

1. The Ear.- Supplementary measurements with the ear are quite desirable because sound-proofing is usually installed in buildings to suit the hearing. Such observations were taken in the course of this investigation.

2. Instruments- For more accurate work it is necessary to obtain quantitative measurements with instruments.

a. Telephone Receivers.- An arrangement could be used as shown in Fig.5. A Bell telephone receiver a is placed near the source of sound in room A; b is a similar receiver placed in front of the duct in room B. By means of the double pole double throw switch at c, an observer at d may listen alternately to the source of sound or the sound transmitted to room B through the ventilation pipe. A variable resistance e allows the intensity of the two sounds to be made equal according to the estimate of the ear.

b. Telephone Transmitters.- A more sensitive arrangement than the one mentioned is shown in Fig.6, in which carbon transmitters are used instead of receivers.

c. Resonators.- In order to reduce the complexity of the sounds and make the comparisons of the two sounds more accurate, resonators were attached to the telephone receivers and transmitters to amplify the definite pitch used.

d. Amplifying Arrangement.- Since the intensity of the transmitted sound becomes very weak as the various absorbing features are added, a further amplification is necessary. This is accomplished by means of the audion bulb circuit shown in Fig.7.

e. Audibility Meter.- As a check on the observations already taken or to determine the audibility of the sounds from the two sources, an audibility meter was used as shown in Fig.8.

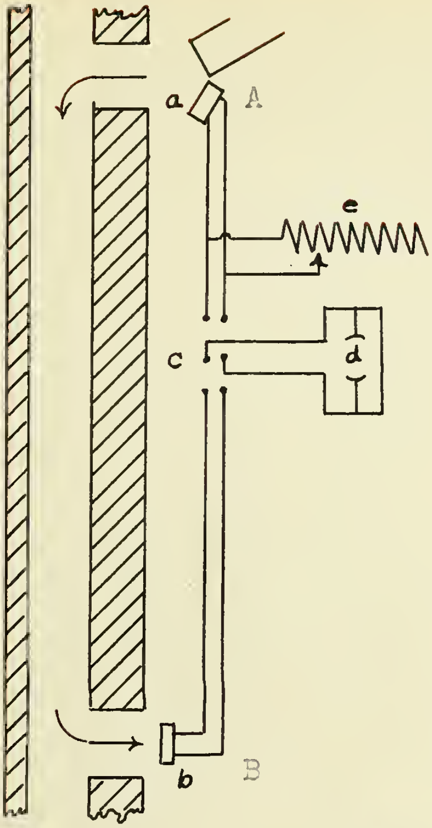


Fig.5

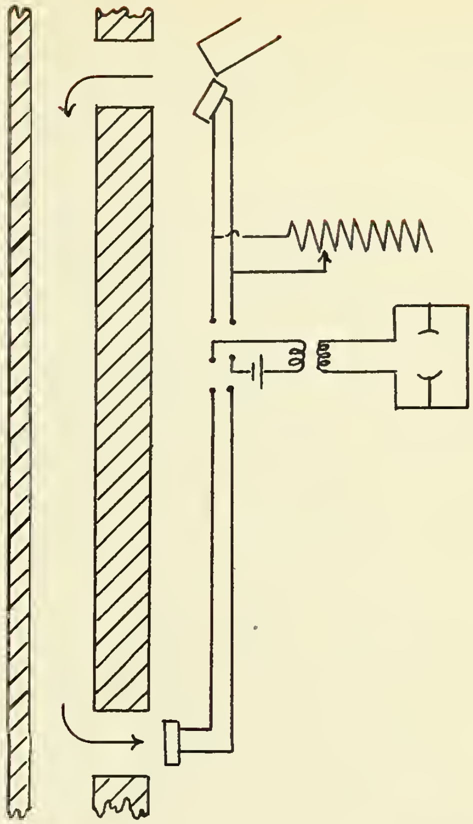


Fig.6

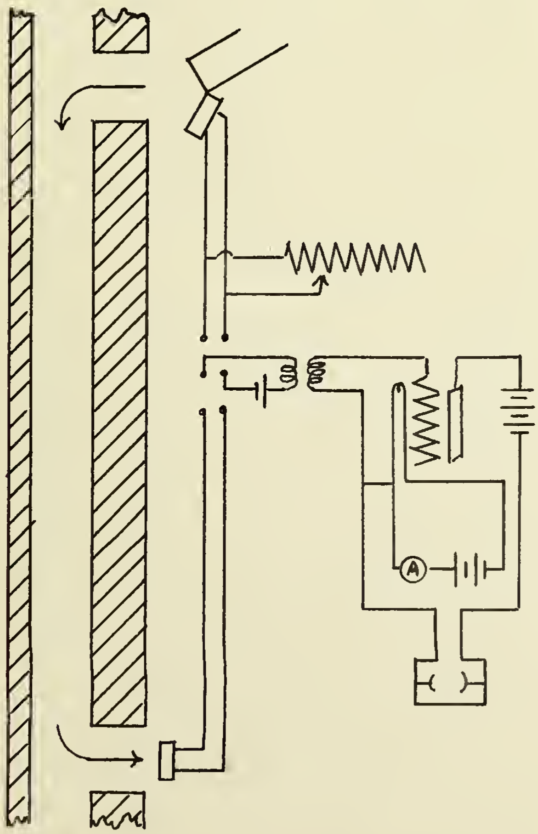


Fig.7

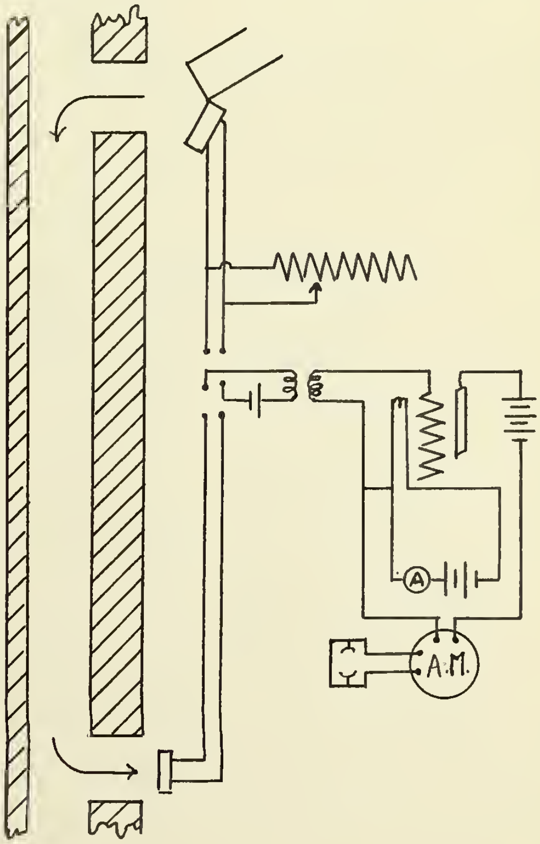


Fig.8

This consists of a constant impedence variable shunt so arranged that the audibility of one sound may be compared in relative terms to the audibility of a sound from a constant source.

f. Devices to Stop Sound.- Sound in a ventilation duct will be transmitted to considerable distances with small loss unless transformed into some other kind of energy. It is not sufficient to reflect or scatter sound waves for the energy cannot be destroyed in this manner. Usually the sound is transformed by means of friction into heat energy.

Various devices may be used to bring about this change in the form of energy, but several factors must be taken into consideration in their selection, such as eddy currents, frictional resistances, and absorption. Furthermore, sound insulators must be designed in such a manner that they will not be impractical from the standpoint of the ventilating engineer's point of view.

Sound insulators which will produce these results to a greater or less degree are concentric chambers, baffles, hair felt linings or combinations of devices of this nature.

V RESULTS OF INVESTIGATIONS

1. Experiments in the Smith Memorial Music Building.- The ventilation system was not as sound-proof as desired and appeared to be the greatest drawback in the control of sound in spite of the fact that each room was equipped with a separate inlet and outlet duct, and that four independent ventilating systems were installed to furnish air to four groups of rooms to lessen the chance for the transfer of sound from one group to the others. This system was installed as shown in Fig. 8, which is the method regarded as the most satisfactory for the complete diffusion of the air in a room.[12]

12. Harding, L.A. and Willard, A.C. "Mech. Equipment of Buildings"

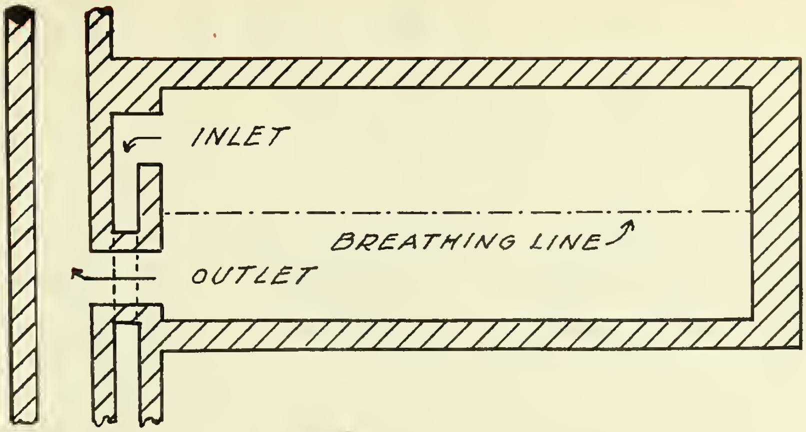


Fig.9.

a. Outlet Pipes.- Experiments conducted in the building after its completion brought out the point that sound was transmitted through the vent pipes to the attic space where it then passed down other vent pipes, particularly those adjacent to the one emitting the sound. For instance, a sound generated in Professor Van den Berg's studio (Room 113) on the first floor, south corridor, passed through a vent pipe to the attic and then down other vent pipes so as to be easily heard in Professor Johnson's studio (Room 315) on the second floor, and a practice studio (Room 306) on the third floor, as well as in the Women's Chorus Room in the basement, directly under Room 113. These vent pipes were arranged as shown in Fig.10. Fig.11

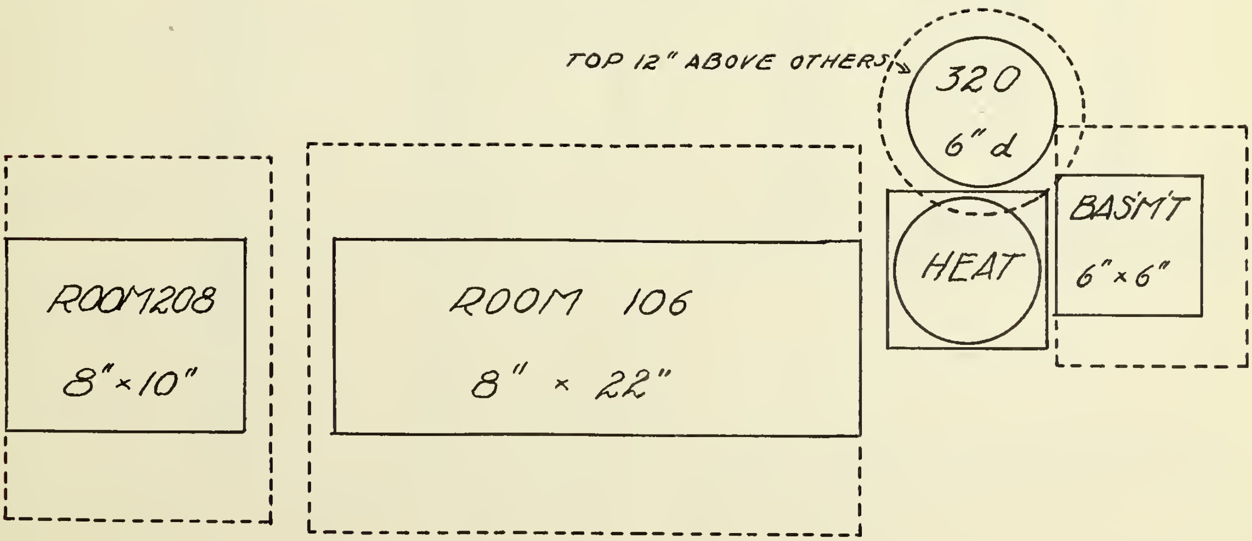
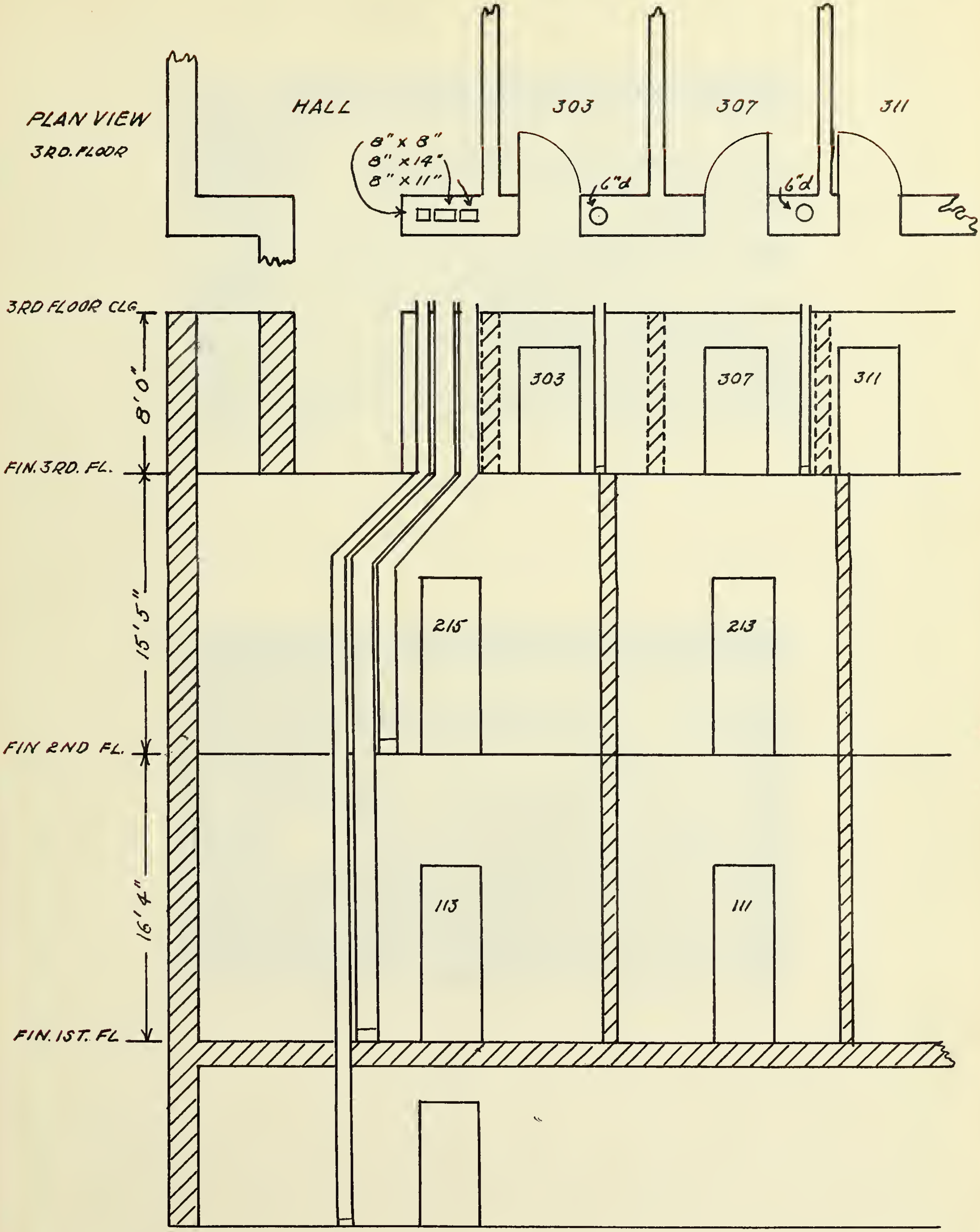


Fig.11.



Outlet Plan for S.W. Corner Section

Fig. 10

Fig.12

Fig.13

Photographs showing the entrance of vent pipes from Rooms 106, 208, 320 and from the basement into the attic space.

shows another typical case where these vent pipes enter the attic and illustrates the possibility for sound transmitted through them, to pass down adjustment pipes to other rooms. Figs. 12 and 13 are photographs showing the entrance of this particular set of pipes into the attic. In this case a sound generated in a practice room (No. 320) on the third floor, north corridor, passed through a vent pipe to the attic and then down other vents so as to be easily heard in Room 208 on the second floor, Room 106 on the first floor, and in the basement room.

To reduce the transmission of sound through these pipes caps were designed to fit over each of them in the attic space as shown in Fig. 14. The attic portion of a typical vent pipe is shown at a, b is the

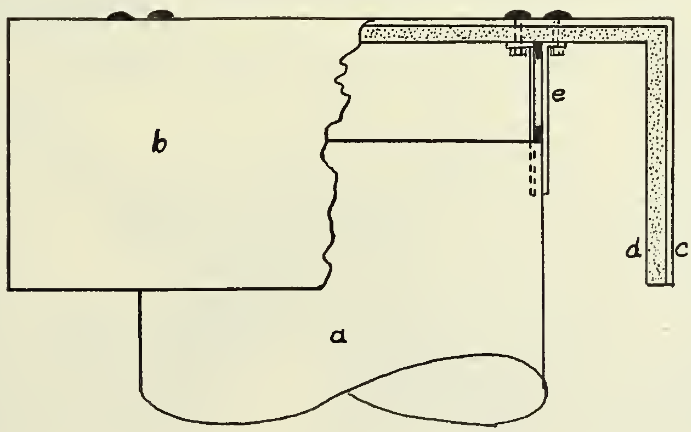


Fig.14

cap designed to minimize the possibility of the transfer of sounds between this pipe and adjacent pipes, c is the galvanized iron body of the cap, d the hairfelt lining, and e supports to hold the cap on and over the pipe. The dotted lines in Fig.11 show the outline of a set of these caps for this particular set of pipes. Fig.15 is a

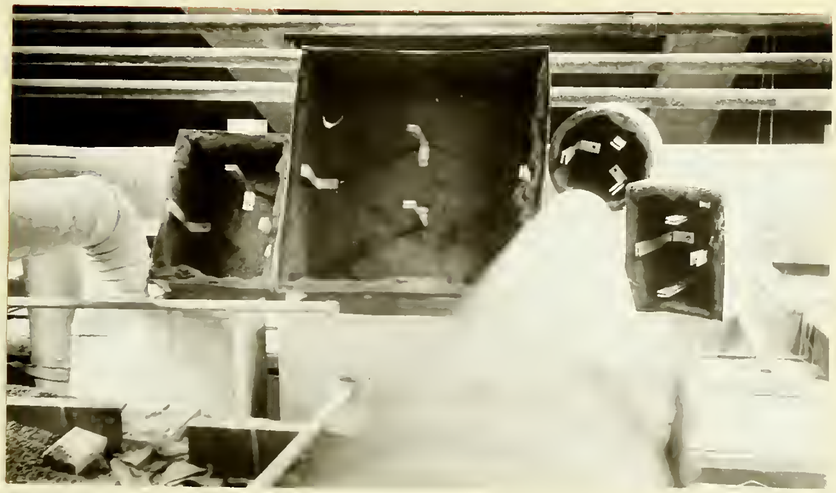


Fig.15

Fig.16

photograph showing the caps resting on the particular pipes for which they were designed, and Fig.13 shows them installed.

Observations made with these caps in place and removed from the pipes, verified the assumptions made. For example, when a sound was generated in Room 113 the intensity of the sound entering Room 215 and Room 303 was practically negligible so long as caps were placed over the pipes from Room 113 or when the cap was placed over the pipe from Room 113 and the caps for the pipes from Rooms 315 and 303 removed. When the caps were placed over the entire set of pipes a sound generated in any one of these rooms was greatly diminished in its transmission to other rooms. It should be stated that these caps scarcely affect the ventilation.

Consideration was now given to a means of minimizing still further the intensity of sounds passing through these vent ducts. Hairfelt was placed on the walls and bottom of the pipes where they entered rooms. Observations showed very clearly that the hairfelt lining cut down the intensity of the transmitted sounds.

Another device consisted of a series of baffles, made of wood, padded with hairfelt. A marked decrease in the intensity of the transmitted sounds resulted when these baffles were installed in the outlet register boxes as shown in Fig.4. For example, with the source of sound in Room 113, a decrease was noted in the intensity of the sounds transmitted to Rooms 215 and 303 when baffles were installed in the register box in Room 113. A further decrease in the intensity was noted when baffles were also installed in the register boxes in rooms 215 and 303.

Additional observations were made with the three insulating devices previously described, namely the caps on the vent pipes in the

attic space, the hairfelt lining in the register boxes, and the baffles in the register boxes; arranged in various combinations. When these devices were used together little or no transmitted sound could be detected, showing that they afford a satisfactory means for the control of the sound in ventilation pipes.

Little or no effect was noted in the intensity of the transmitted sounds when stops made of galvanized iron padded with hair felt as shown in Figs. 17, 18, 19 and 20, were placed in front of the outlet chambers.

b. Inlet Pipes.- Inlet pipes permitted sounds to be transmitted from one room to another as well as the outlet pipes. The investigation was now directed to these inlet pipes.

Four independent fan systems are used in the building to furnish air to four groups of rooms, so that the transfer of sounds from one group to the others is lessened. One system supplies all of the studios, one supplies the recital hall, and two others, situated on the third floor, supply the practice rooms.

The inlets are all placed above the breathing line as shown in Fig.9, which is the proper location, according to the best authorities on ventilation to give a complete diffusion of the air in a room. The inlets for the rooms already discussed (Nos.113, 215 and 303) and which serve for this investigation since they present typical cases, are arranged as shown in Fig.31. The inlets for Rooms 113 and 215 pass down through the corridor wall to the basement where they are connected to the system supplying air to the studios. The inlets for the practice rooms (Nos.303, 307, etc.) pass up through the corridor wall to the attic where they are connected to the system supplying air to the practice rooms on the south side of the

Fig.17

Fig.18

Fig.19

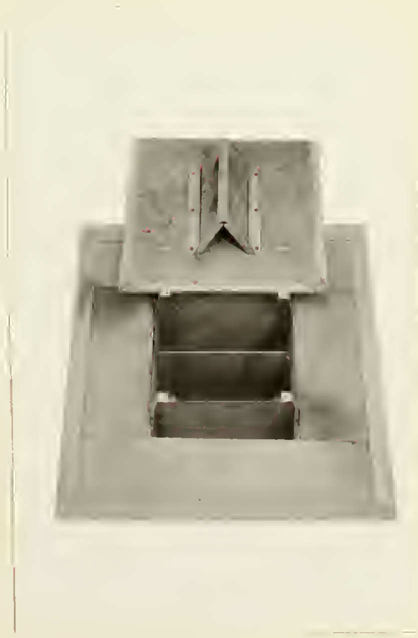
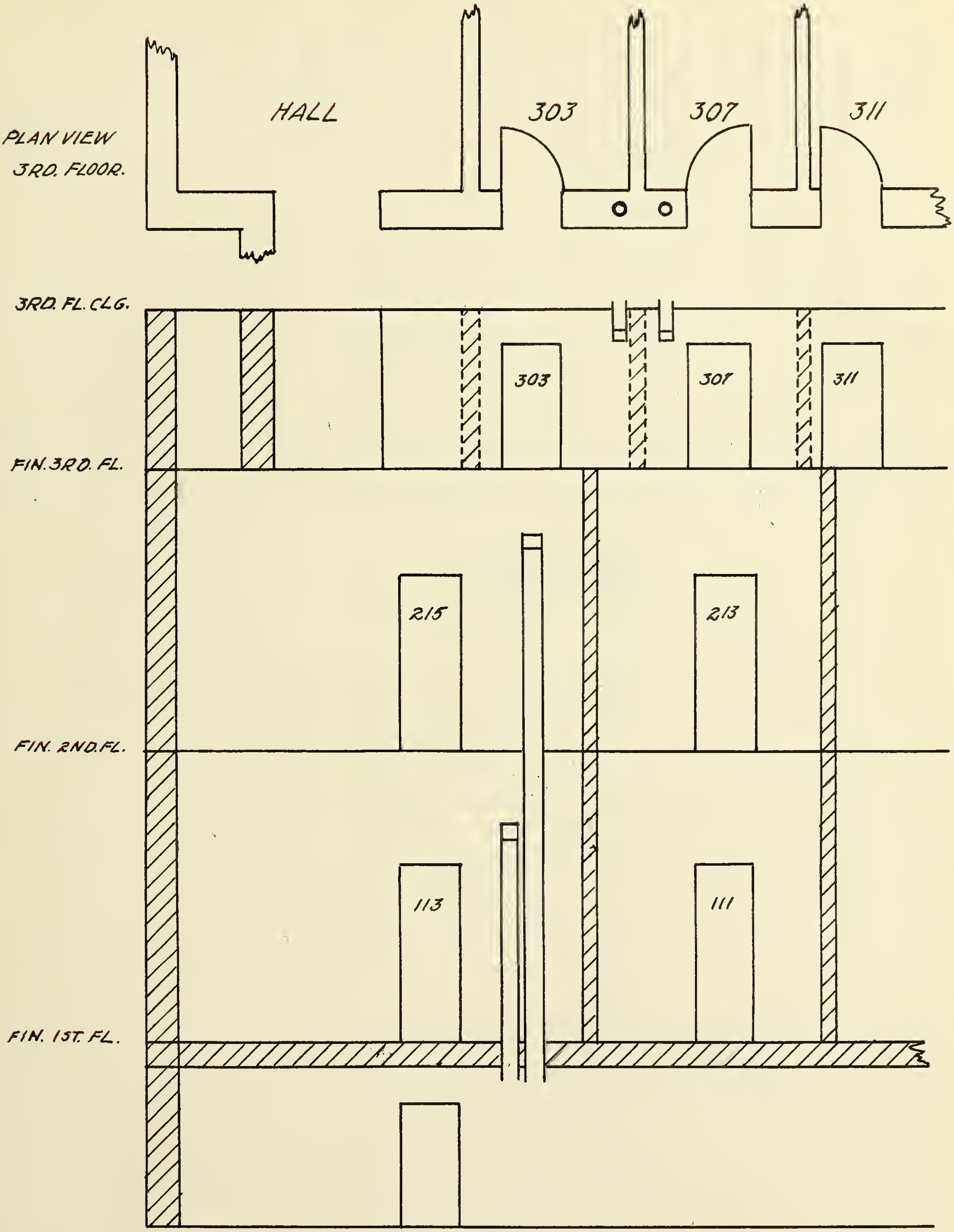


Fig.20



Inlet Plan for S.W. Corner Section

Fig.21

building.

Unfortunately, caps cannot be placed over these pipes as in the case of the outlet pipes, therefore the information obtained in the previous investigation is not directly applicable in-as-far as the inlet pipes are concerned.

The register boxes connecting the inlet pipes to the rooms are similar to those used in the case of the vent ducts except for the fact that "splitters" are installed as shown in Fig.22. Constructions similar to those used in the outlet register boxes were installed in the inlet boxes and the observations repeated. The results agreed with the observations made in the previous case and the intensity of

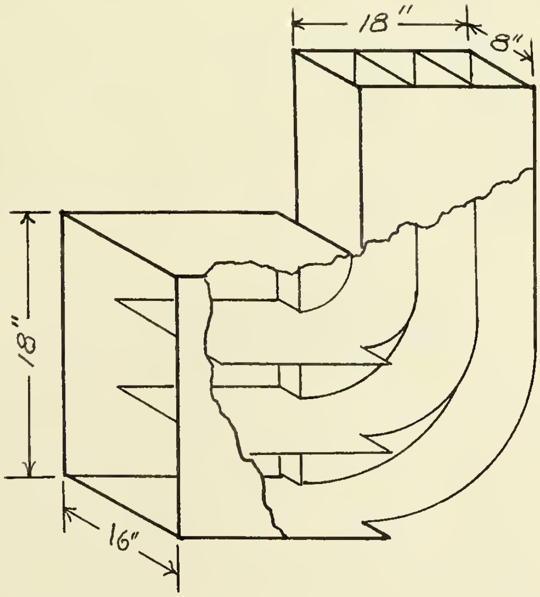


Fig.22

the sounds transmitted from one room to another through these pipes was practically negligible. Without these insulation devices it was observed that the transmitted sound was greater in rooms directly adjacent to the sound; that is, rooms directly over, under, and by the side of the room containing the sound source, but this is to be expected if the friction at the elbows, etc., in the systems are

taken into consideration. Snow in his bulletin "Voice Pipes" also brings out this point.

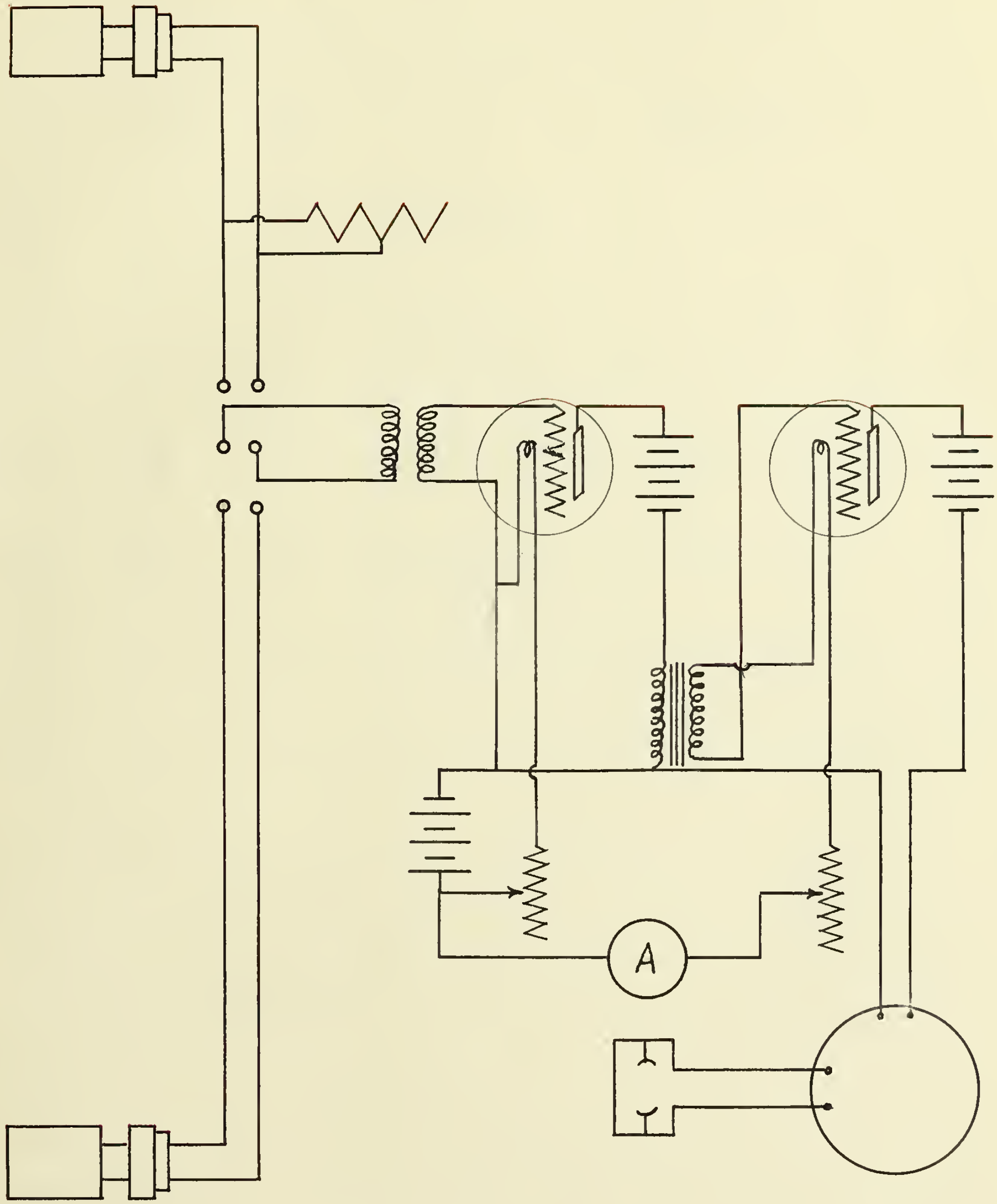
Ventilator stops were placed in front of the inlet registers so as to cause a spreading effect of the air current. These stops did not have an appreciable effect on the sound and are impractical from the standpoint of the ventilating engineer and were therefore discarded.

A further test was made regarding the intensity of the sound transmitted through these inlet pipes, with all insulating devices out of the system, namely, the air current was turned on and off and observations made but no difference was noted. This was to be expected since the velocity of the air was only 0.08 meters per second and the velocity of sound in air is 337 meters per second. A higher velocity of the air would no doubt have generated a new sound, namely, a hum of the grill, which would not have been affected by the devices installed.

2. Experiments in the Physics Building.- Further experiments in connection with this investigation were carried on in the Physics Building at the University of Illinois, which was conveniently equipped with research facilities. Many of the troubles experienced in the ventilation systems in the Smith Memorial Music Building as well as in other buildings, where such systems are used, are likewise experienced in this building. The work could thus be carried on effectively and without interruption, which was not true in the case of the Music Building.

A typical case selected for investigation was the ventilation duct between Room 317 on the third floor, and Room 217 on the second floor. The general method of attack previously described was used,

a tone variator being installed at the constant source of sound and the ear and the various other devices described above as the receivers. The tone variator was placed in front of the grill in Room 317. A Bell telephone receiver, to which a Helmholtz resonator was attached, was placed near the variator and connected to the double pole double throw switch in Room 211 as shown in Fig.33. A sensitive telephone transmitter to which was connected a Helmholtz resonator set for the particular pitch emitted by the tone variator was then placed in front of the grill in Room 217, and also connected to the switch in Room 211. An induction coil, a two stage amplifier, an audibility meter and finally a wireless head set were likewise connected to this switch as shown in the diagram. When the audibility meter was thrown out of the circuit and the double pole double throw switch moved back and forth, the intensity of the sound from the two sources, Room 317 and Room 217, could be balanced against each other by means of a variable resistance placed in the circuit leading from Room 317. The variable resistance was placed in the circuit from 317 as the intensity from this constant source remained the same at all times while the intensity of the sound from Room 217 varied according to the insulating devices installed in the pipe. As a further test on this system an audibility meter was thrown in the circuit and readings taken of the audibility of the sound from the two sources after they had been balanced against each other by the first method. The results checked showing that the ear is very sensitive for comparisons made in this manner. A difference of a tenth of an ohm in the variable resistance could be detected very easily in the first method of balancing the intensity of the sound from one source against the intensity of the sound from the second source. Data was taken for



Arrangement of apparatus as used during the experiments in the Physics Building

Fig. 23

these observations as shown in Table I.

TABLE I

Observations made in the Physics Building

Test No.	Room No.	Audibility	Ohms Res.	Remarks
1	317	74	0	
	317	74	1.6	Flue free
2	217	46	0	
	317	46	1.0	4 baffles in flue in Room 317.
3	317	36	0	Same as test No.2 with a similar set
	317	36	0.8	of baffles in flue in Room 317.
4	217	29	0	Same as test No.3 with 4 baffles just
	317	29	0.6	back of grill in Room 317.
5	317	22	0	Same as test No.4 with 4 baffles just
	317	22	0.5	back of grill in Room 317.
6	217	18	0	Same as test No.5 with 4 more baffles
	317	18	0.4	just back of grill in Room 217.
7	217	14	0	Same as test No.6 with 4 more baffles
	317	14	0.31	just back of grill in Room 317.

The data given in Table I are given in a curve (Fig.34) in which the resistances which were introduced into the 317 circuit to diminish the intensity of the sound from the source in Room 317 to the intensity of the sound transmitted to Room 217 were plotted as the abscissae and the audibilities of the transmitted sound as the ordinates. This curve shows the decrease in the intensity of the transmitted sound as the various insulating devices were installed, and also gives the direct relation between the audibility of the transmitted sound and the resistance necessary to reduce the intensity of the source sound to that of the transmitted sound.

Fig. 24

VII. DISCUSSION OF RESULTS AND RECOMMENDATIONS

The investigation brings out the following points: That sound is transmitted from room to room through continuous piping; that there is less loss of intensity in large pipes than there is in smaller ones; that pipes themselves are set in vibration if their walls are thin compared with their cross-section; that outlet pipes opening into an attic space allow the transmission of sound from room to room; that linings in pipes cause a part of the sound energy to be transformed by means of friction into heat energy; that the air current has practically no effect upon the sound waves; that the intensity of the transmitted sound is greater in rooms directly adjacent to the sound, that is, rooms directly over, under, and by the side of the room containing the sound source; and that transmitted sound may be controlled.

In accordance with these points brought out, the author recommends that separate systems should be used for various sets of rooms in order to lessen the chance for the transfer of sound from one group to the others; that pipes should be made of non-vibrant material so as to avoid new sounds being created within the pipes themselves as well as to prevent the communication of these sounds to other

pipes by means of sympathetic vibrations; that caps similar to those previously described be placed on pipes which open into an attic space; that pipes be lined with some sound deadening material; that a series of baffles be installed in the chambers connecting the room to the pipes or in the case of thin walls where chambers are not used, in the pipes themselves; that inlets be placed in the room above the breathing line; that outlets be placed in the room near the floor and on the same side of the room as the inlets and that pipes from different rooms be placed as far apart as possible.

The author desires to express his appreciation to Dr. F.R. Watson who suggested this problem, for his continued interest and suggestions during this investigation.